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ANALYSIS OF SMALL CALIBER MANEUVERABLE
PROJECTILE (SCMP) CONCEPTS FOR
HELICOPTER AND AIR DEFENSE APPLICATIONS

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I. INTRODUCTION

In air to air engagements with mobile threat helicopters, the possession of a round of ammunition which could depart from a normal flight trajectory to engage a maneuvering enemy target would be of great value. Maneuvering projectiles launched from an automatic cannon would have the added benefit of putting a number of rounds on target in a short time. The FC&SCWSL has initiated the development of such a projectile. In the sections that follow results of analytical investigation of the explosive thruster concept, which is only one of several maneuvering techniques, are described.

II. SCMP CONCEPTS

Recent technology developments in private industry suggest the possibility of developing a small caliber maneuvering projectile weapon system. Specific technological advances have been made in the areas of guidance system design, sensor technology, projectile maneuver control, projectile configuration design, packaging of microcomponents and g-hardening of projectile components. Several concept designs of small caliber maneuverable projectile systems, in calibers varying upwards from 30mm, have been proposed by several private industries. Significant technological advances have been made in the development of critical subsystem components. Private industry has been particularly active in the design of projectile control mechanisms and guidance techniques. Among the various proposed projectile concepts now being considered are spin-stabilized projectiles employing either lateral explosive thrusters or a tiltable nose as the maneuver mechanism and fin-stabilized projectiles as controlled by fins, spoilers, ram air jet devices, lateral explosive thrusters or lateral gas jets.

III. AERODYNAMIC ANALYSES OF EXPLOSIVE THRUSTER CONCEPTS

The analyses of the explosive thruster concept were based on a 30mm (and in some cases 40mm) projectile configuration similar in design to a conventional 30mm projectile.

The analyses consist of: 1) a preliminary study of down range deflection resulting from a lateral impulse, 2) a six degree of freedom analysis of the rigid body motions of the projectile subsequent to the application of a lateral impulse, and 3) system performance simulations of SCMP terminal miss distances.

In the preliminary impulse deflection study, a concept configuration for the band of explosive charges was developed, which consists of nine charges approximately 31mm long equally spaced around the perimeter. Each explosive charge imparts an impulse of 1.89 N.s causing a sudden change in lateral velocity of 5.83 m/s. Lateral drift of the projectile is shown to vary linearly with down range distance travelled after the impulse. In effect, the lateral impulse causes the projectile's velocity vector to rotate by a small amount. When the impulse is applied at a later time along the path the amount of velocity vector rotation is increased; therefore, the total lateral displacement depends on the time of impulse application and on the down range distance travelled after the impulse.

In the six degree of freedom rigid body dynamic simulations, the time variations in the angular orientation of the projectile's longitudinal axis and the angle of attack were determined before and after the impulse. Analytical results for the 30mm and 40mm spin-stabilized concept projectiles show that the projectile remains stable after pulse application, even when the pulse is applied after the velocity has slowed considerably. Results for both linear and helical grove configurations are presented in Figures 1 and 2. The figures contain graphs of the angle of attack and the azimuth orientation angle Θ for impulses applied 0.5 sec. after the start of the trajectory. After the impulse, the angle of attack decays, usually in about one second, to a value near the pre-impulse value; however, the helical explosive thruster arrangement results in a much faster decay time of about one-half second. The helical design produces an impulsive moment as well as an impulsive force so that the projectile's angular momentum vector gets instantaneously rotated by the same amount as the linear momentum vector. For the case of a linear explosive element, the angular momentum vector is also realligned, not instantaneously, but rather due to the action of aerodynamic moments affected by the sudden increase in the angle of attack. The prescessional motion of the projectile caused by the sudden increase in the angle of attack lasts for over one second.

Off-centered impulsive loads cause the projectile to oscillate with greater amplitude and, in some cases, increase the settling time. In general, the amplitude of oscillations increases with the pulse application time.

IV. SYSTEM SIMULATIONS OF EXPLOSIVE THRUSTER CONCEPTS

System simulations of the explosive thruster SCMP concept were conducted to determine the overall accuracy of the system for different guidance schemes and to assess the effects of system errors on performance. Three types of guidance system were considered in these investigations. The first scheme determines the required amount of course correction based on repetitive trajectory calculations. Although this technique is not practical for hardware implementation, due to the large number of computations required to generate a solution, it does generate precise guidance commands. Therefore, the trajectory shooting algorithm provides a bound on the performance capabilities of the system. Another type of command guidance scheme considered is based on the AH-1S fire control computer equations. These equations determine how much rotation in the projectile's velocity vector is needed at any time to get back on course. The third guidance scheme analyzed is a target rate sensitive scheme that activates an impulsive correction when the lateral target rate exceeds some threshold. This guidance scheme could be implemented in a homing projectile that contains a sensor to measure the relative target distance and lateral rate.

Major findings of the system performance simulations of command guidance concepts are listed below:

1) One or two impulses are usually sufficient to correct for initial aim error of 5 milliradians in each axis, provided the guidance scheme is accurate and the relative distance to the target is not too small. Nine explosive line elements are sufficient to compensate for an accelerating helicopter target at ranges between 1500 and 4000 meters.

2) Initial aim errors are corrected most efficiently (fewest explosive elements fired) when impulsive firings take place at the earliest possible moment.

3) Errors caused by undetected target acceleration in the down range direction are small unless the target is initially very far down range (greater than 3500 meters). Miss distances caused by undetected target acceleration in the cross range direction are significant if the target range is beyond 1500 meters initially. In either case, explosive thrusters fired at half-second time [illegible]rvals accurately compensate for the acceleration induced errors. F[illegible] demonstrates this point. In the first case, impulsive correction[illegible]plied at only one time (0.5 seconds). In the second case, impul[illegible] [illegible]rrections are determined every half-second along the trajectory. Also presented is a simulation in which there are no impulsive corrections. In addition to the -5 milliradian initial aim error, an error occurs due to undetected target acceleration components of 2 m/s in both the down range and cross range directions. At 0.5 seconds from launch two pulses are fired regardless of the target range. Corrections made at this time effectively remove

the initial gun-pointing error contribution. Afterwards, the miss distance error grows from the effect of target acceleration.

Final miss distances on the order of one meter were obtained in the simulation of the perfect guidance scheme. As is shown in Figure 4 the inexact guidance scheme also resulted in small miss distances for targets at ranges below 4000 meters. Beyond 4000 meters the inexact guidance scheme required more than the nine available explosive charges for full correction.

4) The effects of 20 degrees error in the projectile's roll orientation and a 0.1 to 0.2 second delay in initializing the guidance command were investigated. These errors were shown to cause only a minor increase in miss distance. Figure 5 shows the effect of 20 degrees roll reference error on miss distance. In situations where corrections take place at multiple times along the trajectory the net effect of roll reference error is not large, since subsequent impulsive firings will compensate, in part, for errors induced by previous impulsive firings. The effect of roll reference error for the accelerating target simulation (described previously) in which impulsive corrections are determined every half-second is minimal. The final miss distance errors are less than two meters from the target center in all cases shown and usually are less than one-half meter.

5) Tracking errors (measured position and velocity errors of the projectile and target) significantly affect the miss distance of the SCMP. Miss distances often were increased by two to six meters when representative tracking errors were included in the simulations.

V. PERFORMANCE ANALYSIS OF A SCMP SYSTEM WITH TARGET RATE SENSITIVE GUIDANCE

For the active guidance mode, guidance computations are made primarily by a computer system located on or near the launcher vehicle. For semi-active and homing guidance, guidance computations are made onboard the projectile (in a microprocessor chip). The microprocessor determines course corrections on the basis of target state information provided by an onboard sensor.

In Figure 6 simulation results are presented for target rate homing guidance. The number of charges fired at each pulse time is allowed to vary, depending on the magnitude of the relative target cross velocity. Also, the rate homing scheme is activated only when the range between projectile and target is below some prescribed value. In this way, the simulation can account for the inability of many onboard sensor devices to detect the target beyond a given range. For the simulation shown the rate homing scheme was activated at a range of 500 meters. The system activated at 500 meters fires anywhere from three to all nine explosive thrusters initially. In this case, excellent results were obtained for targets at initial ranges below 3500 meters. The degradation in performance at longer ranges is again due to the fact that more

than nine explosive charges are needed to achieve full correction. Although the rate homing guidance works well, particularly at shorter target ranges, it is not as efficient as the active scheme in conserving explosive charges.

VI. RAM AIR JET CONCEPT DEFINITION AND ANALYSIS

Currently, a maneuverable projectile concept is being developed by Ford Aerospace & Communications Corporational for eventual use on Army helicopters. The baseline concept, shown in Figure 7, is a 40mm fin stabilized projectile that actively maneuvers by means of a ram aim mechanism. About 40 ms after being launched, the projectile will be given a unique address by a milimeter command guidance system onboard the launcher vehicle. A shared aperture guidance system allows the helicopter to track both the target and multiple rounds during the engagement.

Maneuver capabilities of the projectile will depend on a number of factors including the diameter and exit angle of the ram air jet mechanism; furthermore, the moment arm of the control force with respect to the projectile's center of mass is an important design parameter. In Figure 8, the theoretical lateral maneuver accelerations are shown for two design configurations as a function of Mach number.

System simulation of the FACC concept projectile demonstrate that this concept will perform well against enemy helicopters and surface targets at extended ranges. Figure 9 contains results of simulations for three targets -- and for two values of the ram air jet exit angle. Optimal performance is achieved for a 30 degree exit angle. Near zero miss results for targets at ranges up to 3.0 km.

VII. AIR DEFENSE CONCEPTS

A low drag projectile concept containing a hot gas generator mechanism is being considered for use in air defense applications. In Figure 10 the effects of 5.0 mrad aim error is illustrated for an evasive helicopter target. Both a ballistic trajectory and the maneuverable projectile trajectories are shown. More evasive targets were considered including jinking, fixed wing aircraft. The gas jet controlled projectile has no difficulty in intercepting the jinking target, even at ranges beyond 4500 meters.

In conclusion, analytical studies have demonstrated the high performance potential of small caliber maneuverable projectile concepts. These investigations reveal that the SCMP concepts have the performance capability to destroy airborne and surface targets regardless of any in-flight evasive tactics. In the near future, we plan to demonstrate the feasibility of small caliber maneuverable projectile concepts first by designing and testing hardware components, and eventually, by developing and testing a flyable breadboard.

FIGURE 1: **ANGLE OF ATTACK VS TIME SIX DOF TRAJECTORY SIMULATION**

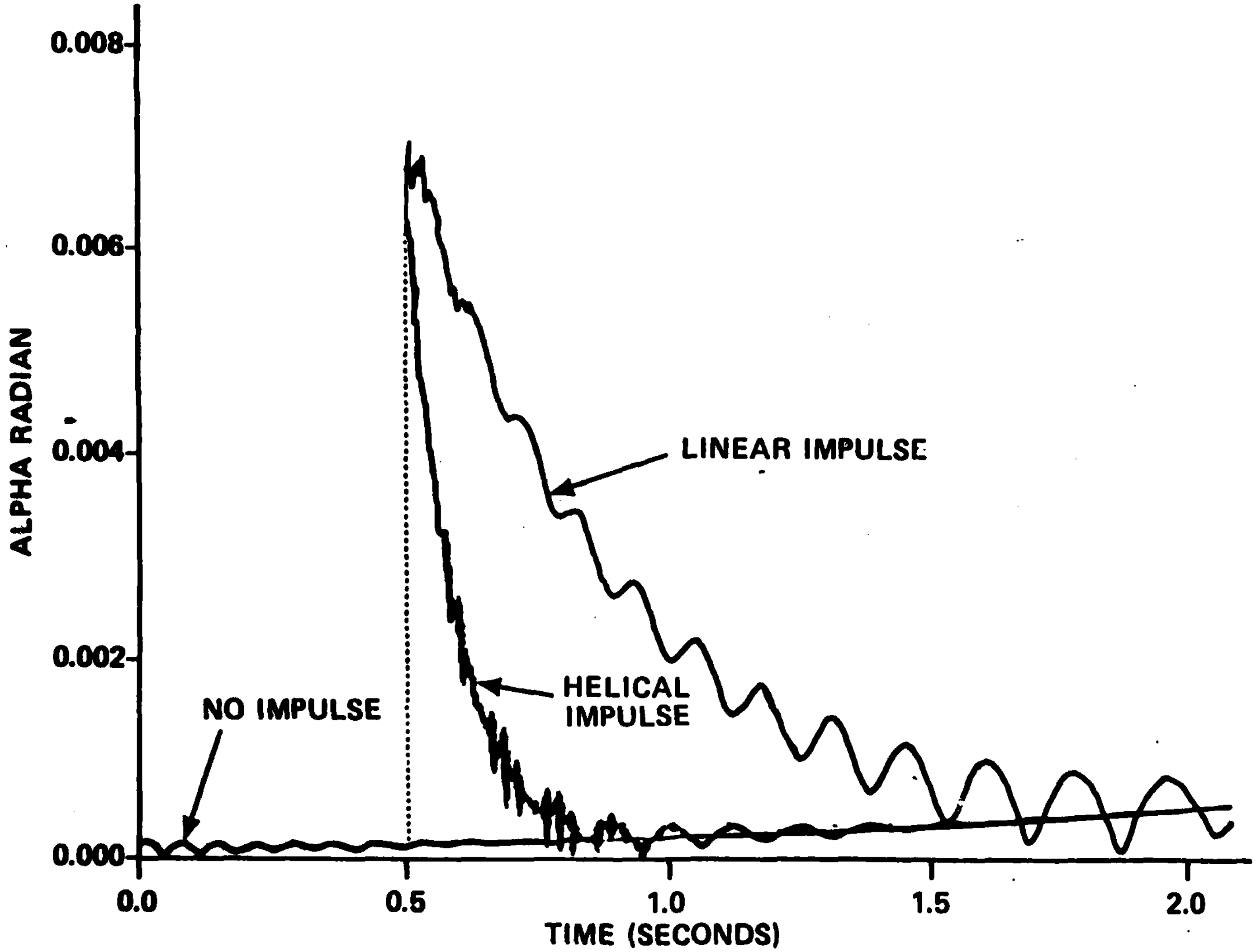

FIGURE 2: **HEADING ANGLE VS TIME**
SIX DOF TRAJECTORY SIMULATION
HELICAL THRUSTER CONFIGURATION

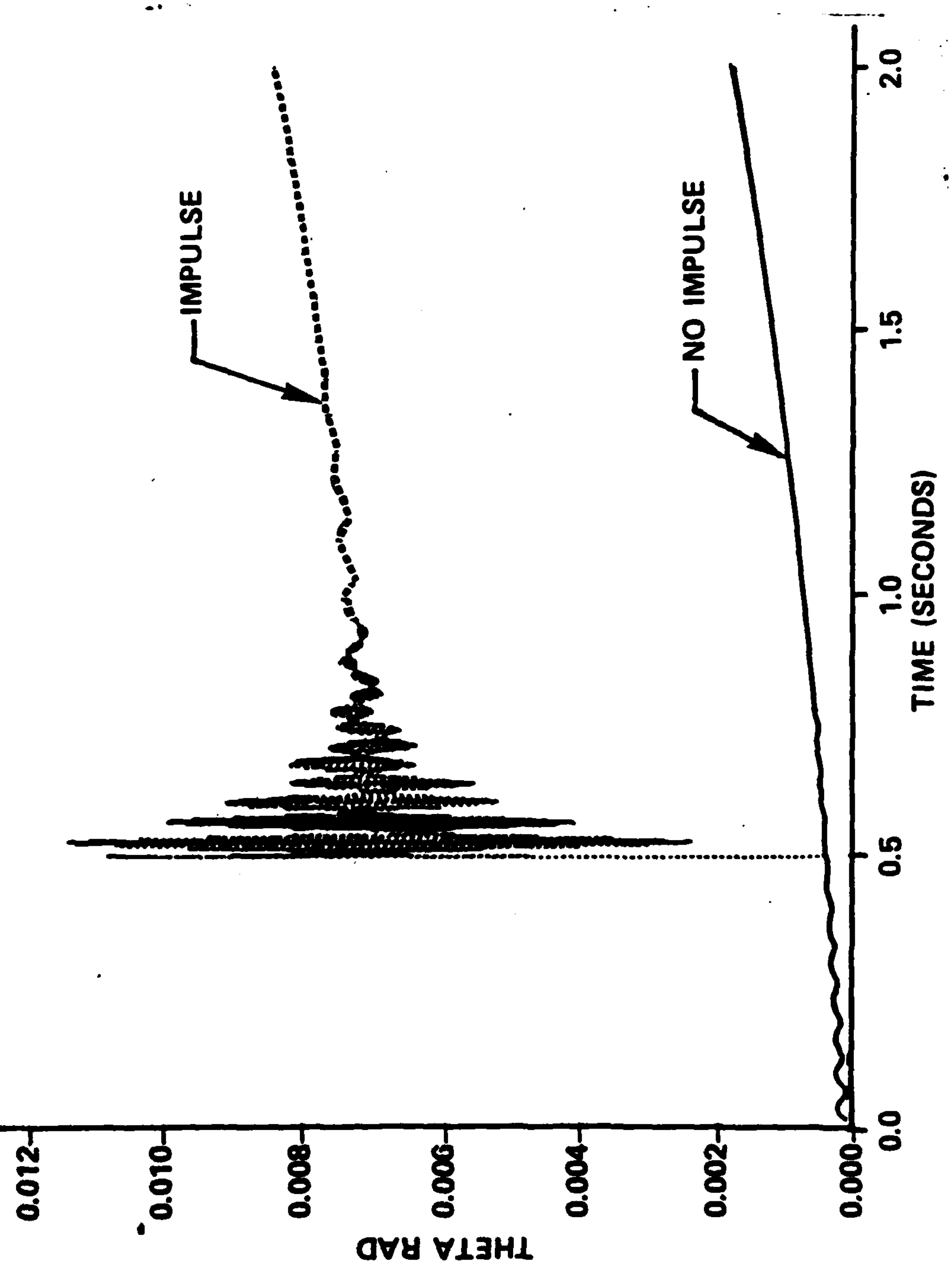

FIGURE 3: PRECISE COMMAND GUIDANCE SIMULATIONS
SPIN STAB EXPLOSIVE THRUSTER PROJECTILE

AZ = EL = –5MR; ATX = ATZ = 2 M/S**2

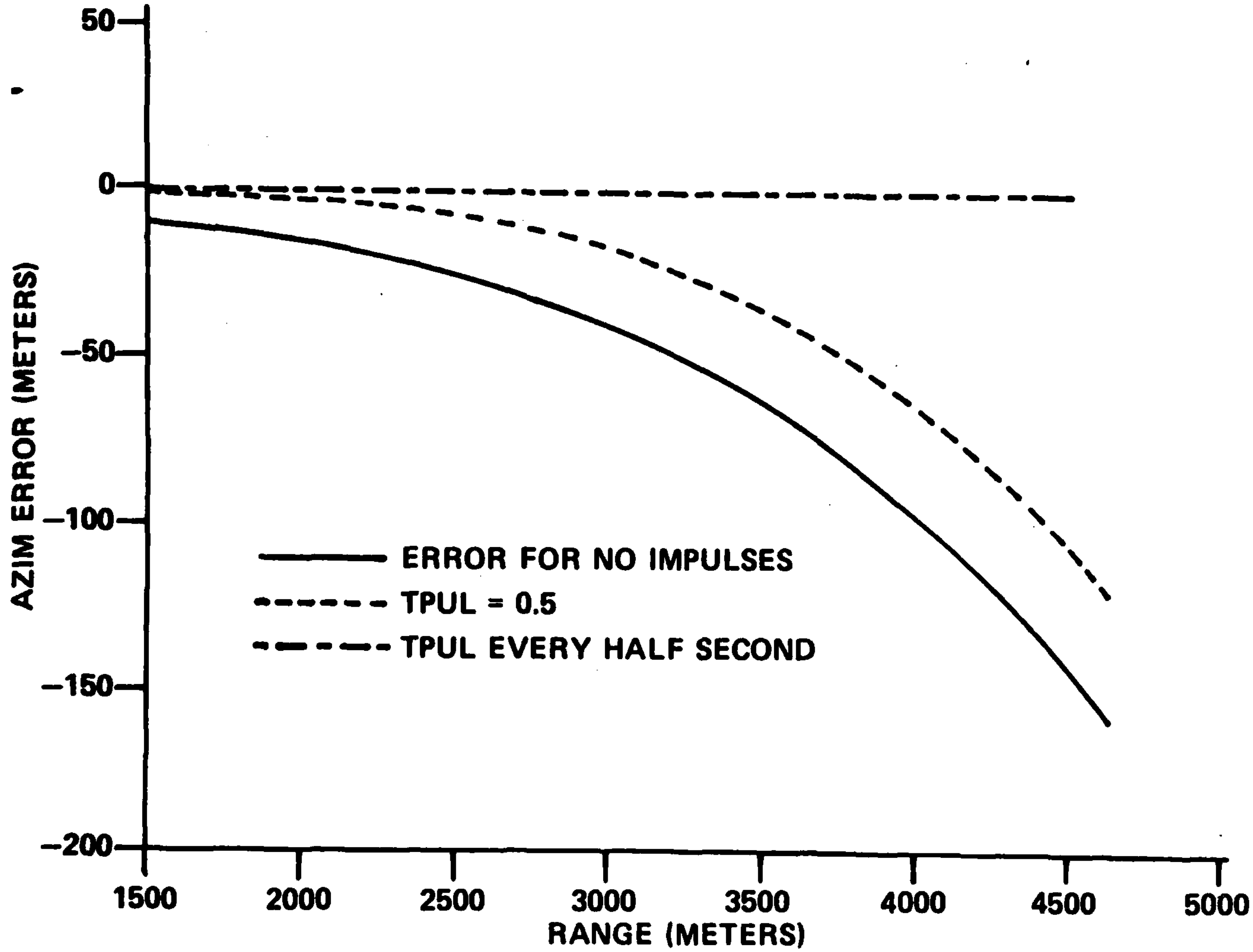

FIGURE 4: **COMMAND GUIDANCE SIMULATIONS SPIN STAB EXPLOSIVE THRUSTER PROJECTILE**

AZ = EL = −5MR; ATX = ATZ = 2 M/S/S
TPUL = EVERY HALF SECOND

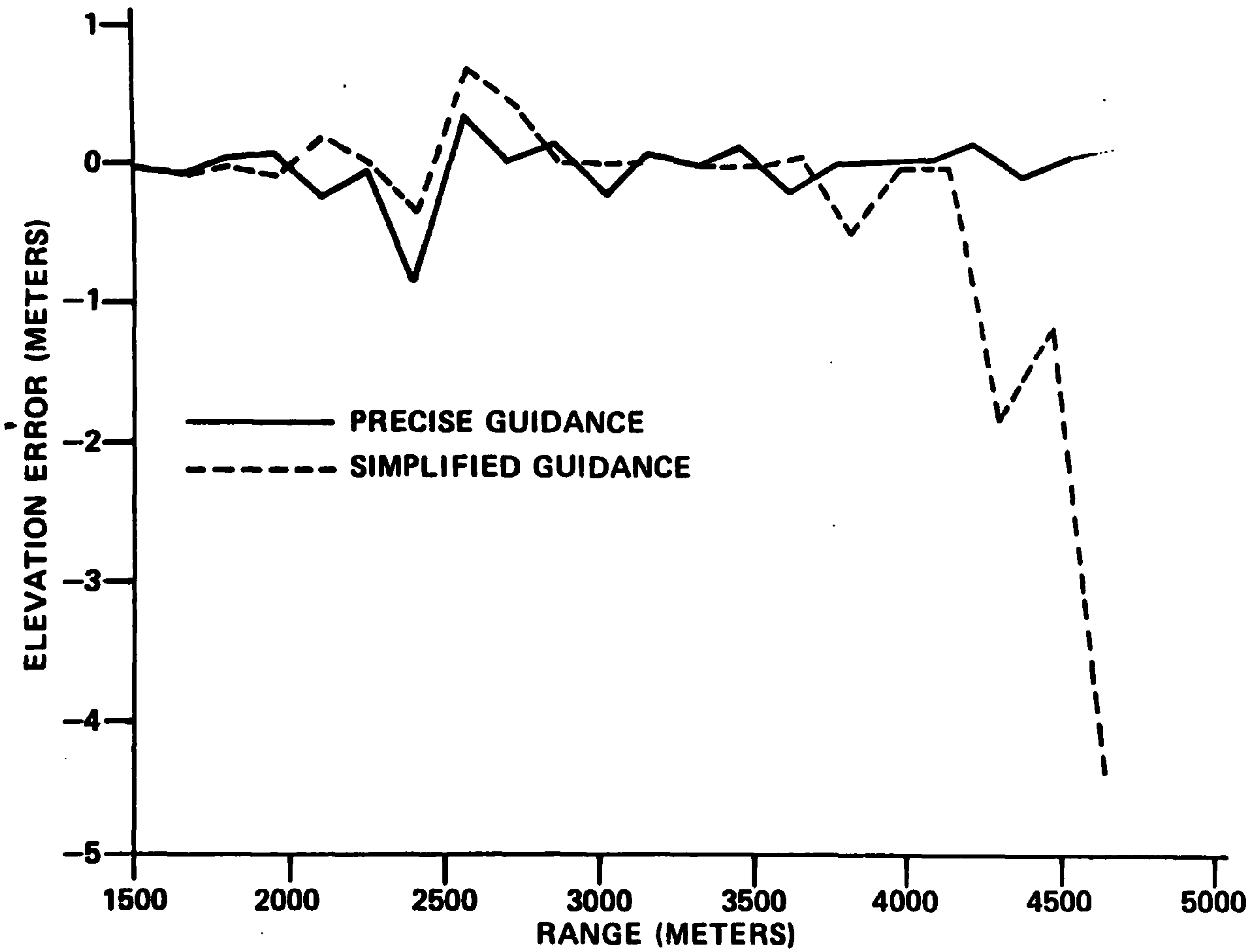

FIGURE 5:

PROJECTILE ROLL REFERENCE ERROR SIMULATION SPIN STABILIZED EXPLOSIVE THRUSTER ANAL

AZ = EL = –5 MRAD

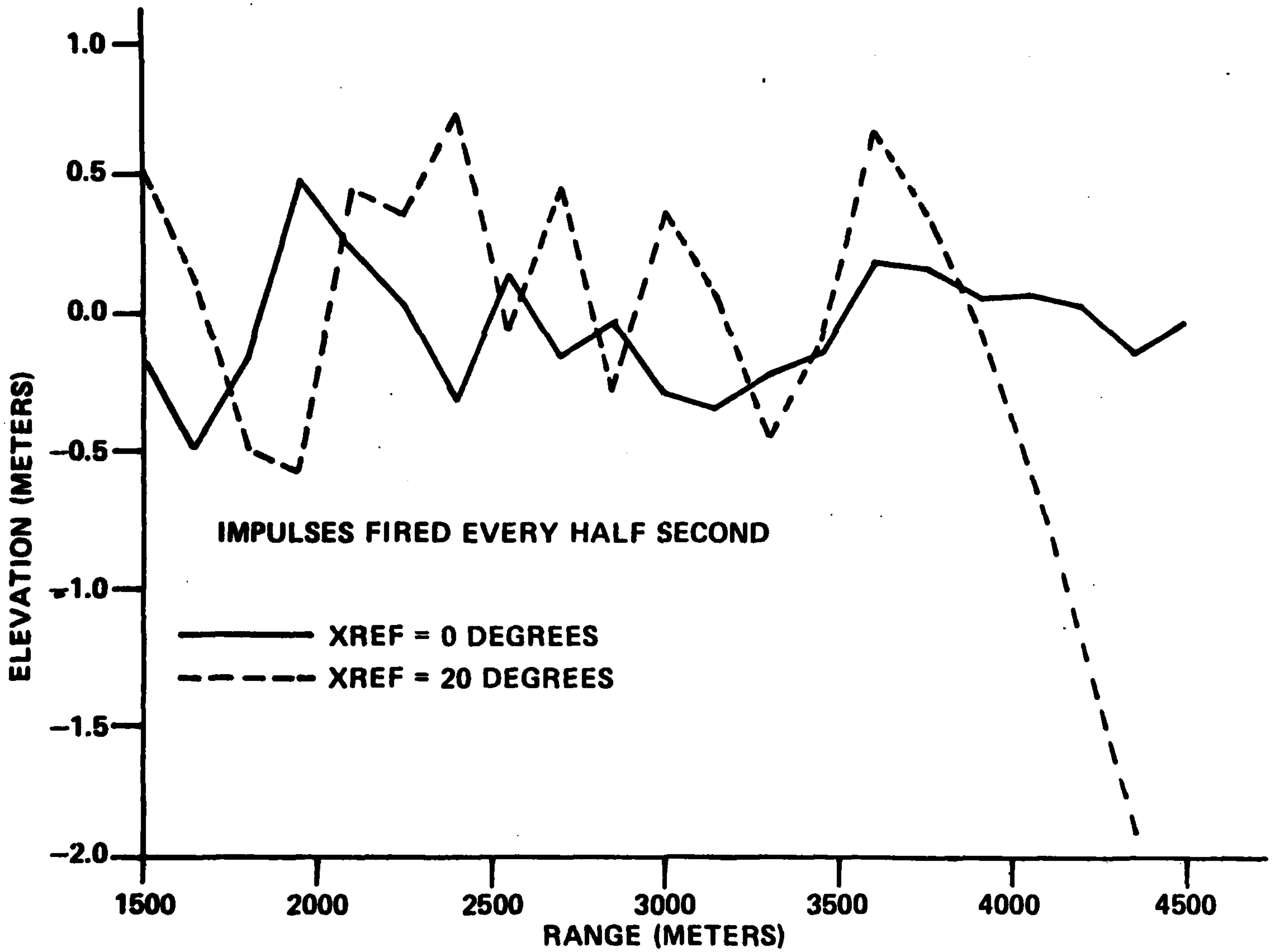

FIGURE 6: RATE HOMING GUIDANCE SIMULATION

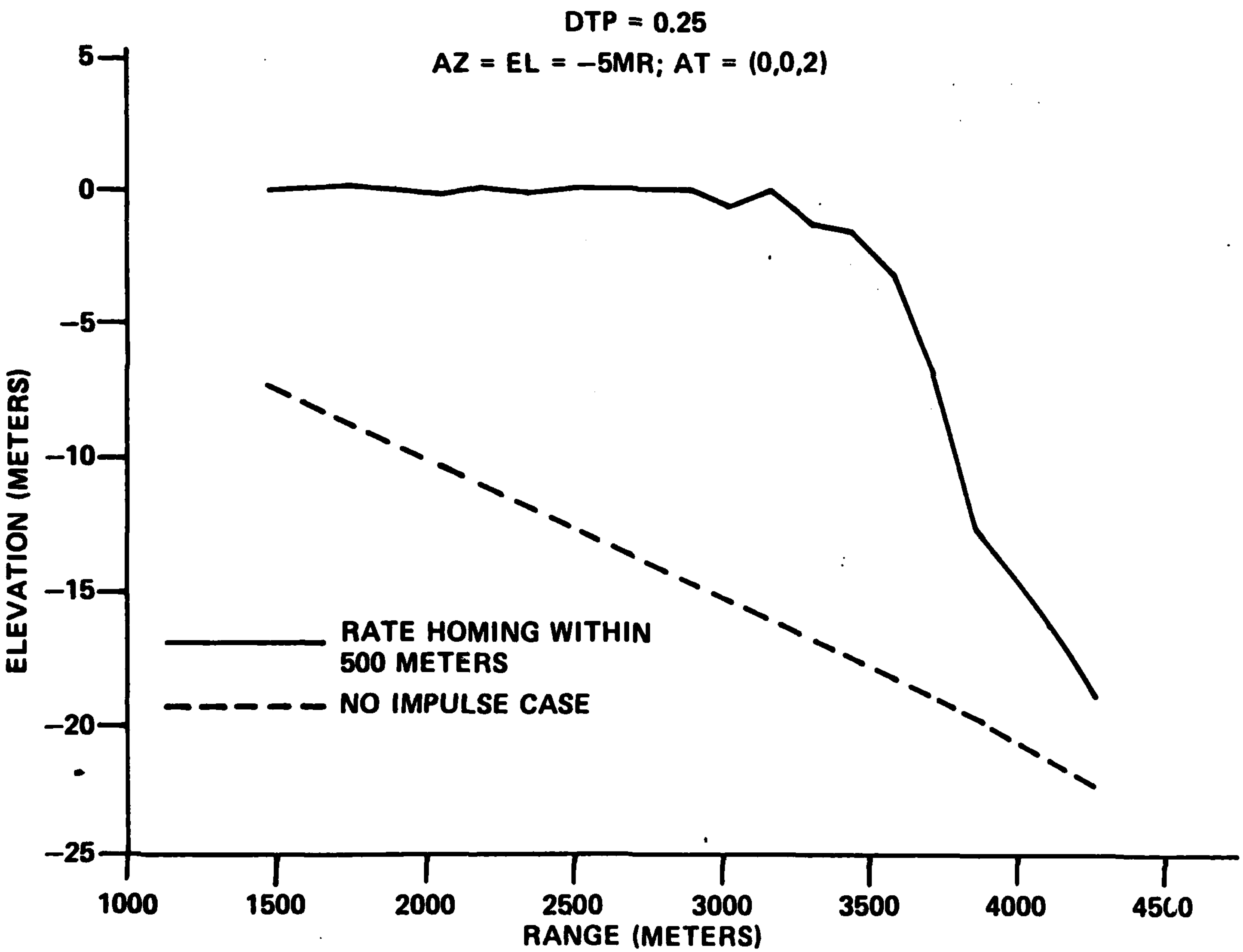

FIGURE 7: *THE BASELINE 40mm PROJECTILE USES RAM AIR CONTROL AND FLEX FINS*

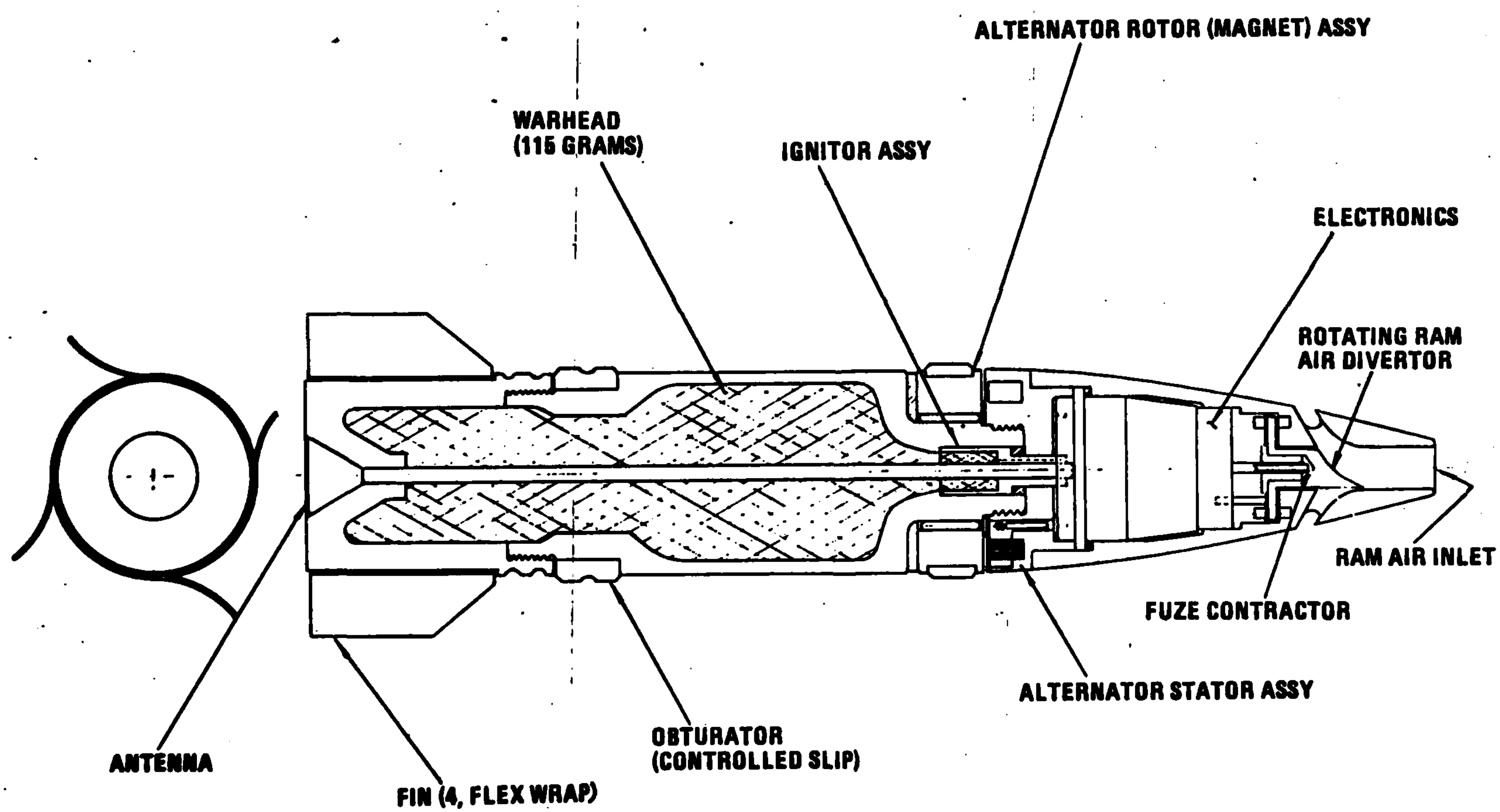

FIGURE 8: *MANEUVER CAPABILITIES*

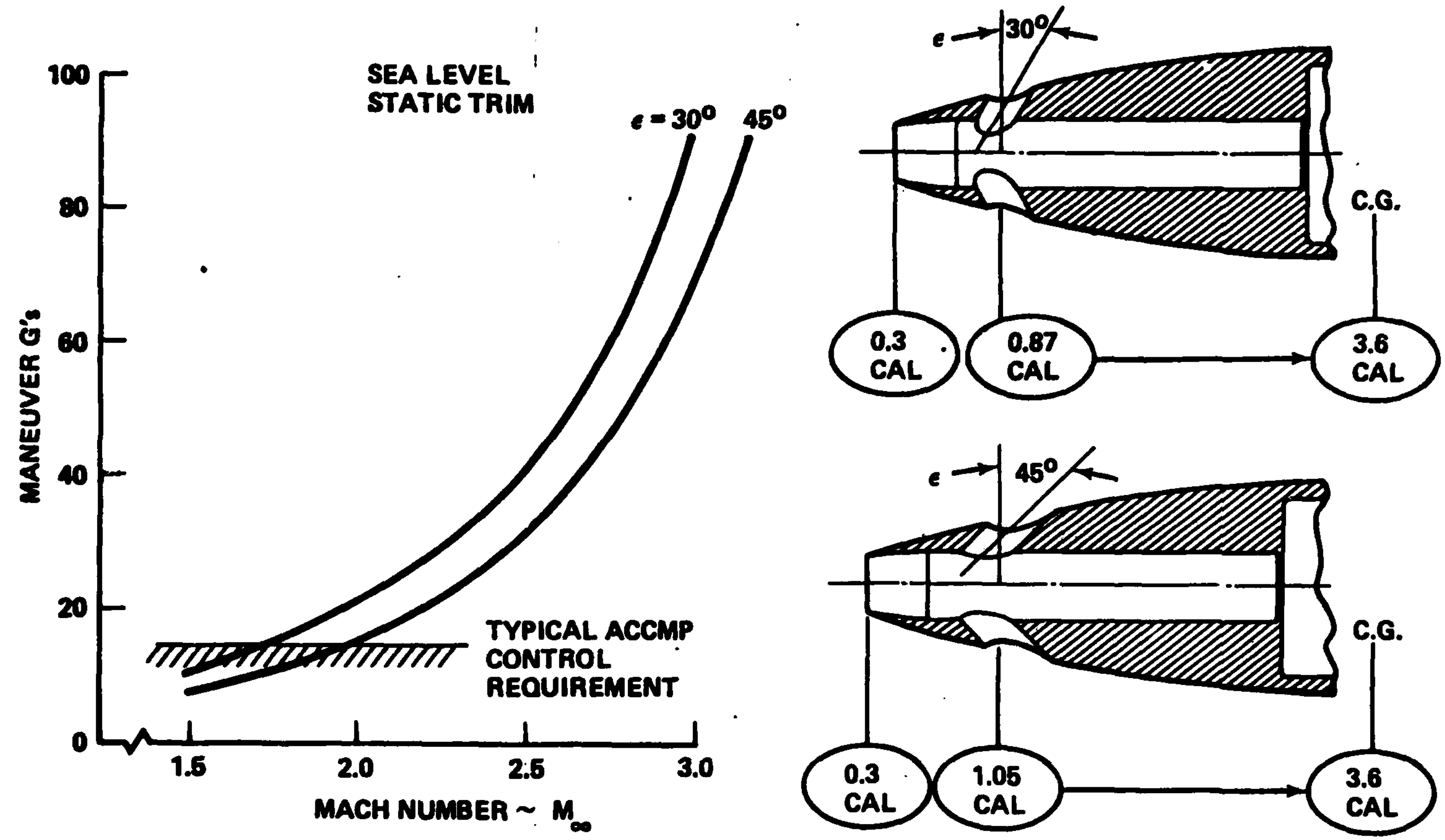

FIGURE 9: *SYSTEM ACCURACY*

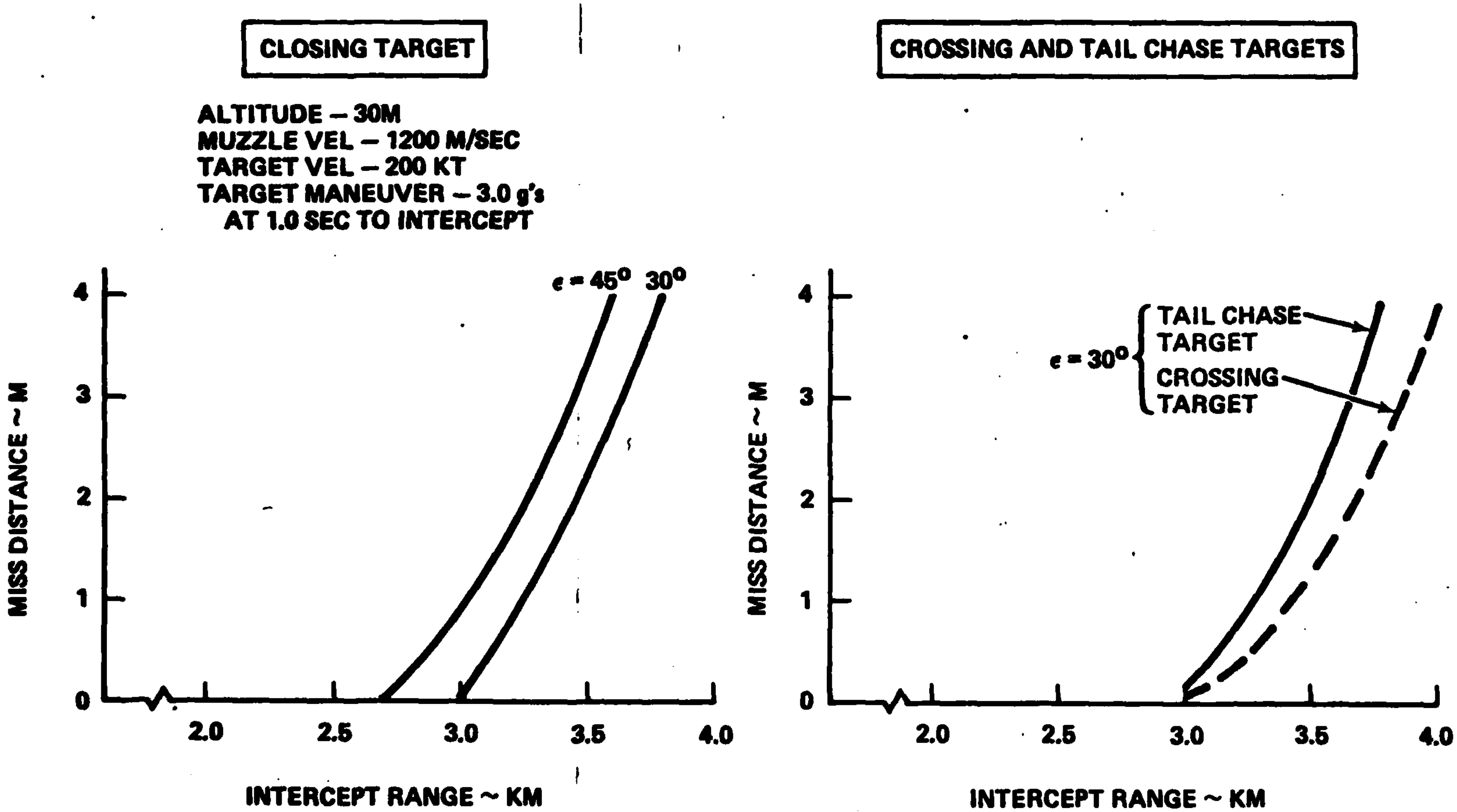

FIGURE 10: FIN STABILIZED SCMP SIMULATION
GAS JET REACTION CONTROL MECHANISM

HELICOPTER TARGET; 5.0 MRAD AIM ERRORS